

(19) World Intellectual Property  
Organization  
International Bureau



(43) International Publication Date  
14 October 2004 (14.10.2004)

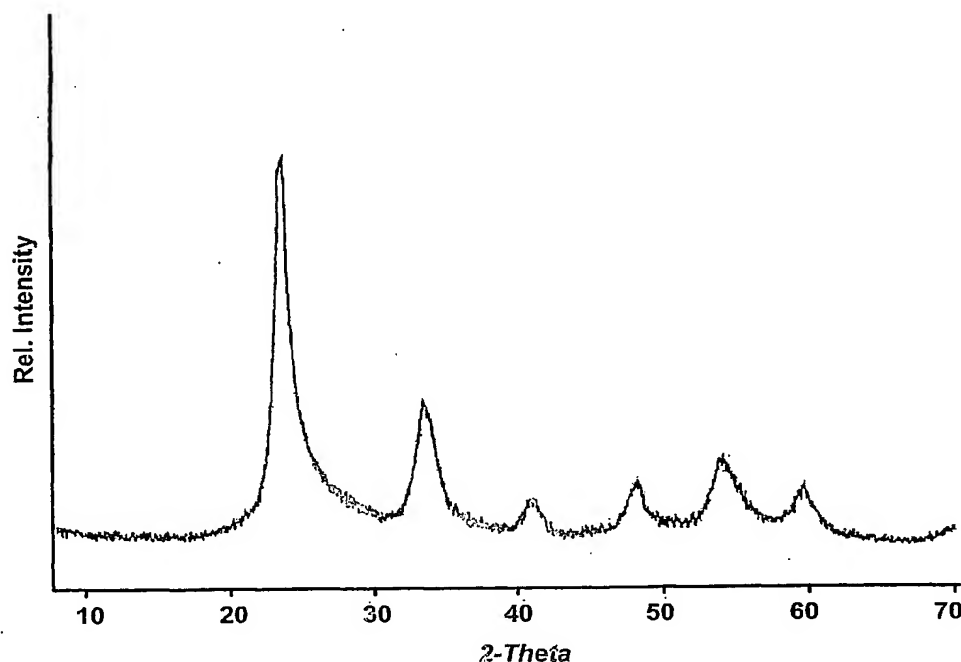
PCT

(10) International Publication Number  
**WO 2004/088780 A1**

- (51) International Patent Classification<sup>7</sup>: **H01M 8/02**, 4/90, C01G 41/02, B01J 23/30
- (21) International Application Number: **PCT/US2004/009019**
- (22) International Filing Date: 25 March 2004 (25.03.2004)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:  
60/320,056 26 March 2003 (26.03.2003) US
- (71) Applicant (for all designated States except US): **OSRAM SYLVANIA INC.** [US/US]; 100 Endicot Street, Danvers, MA 01923 (US).
- (72) Inventor; and
- (75) Inventor/Applicant (for US only): **CHRISTIAN, Joel, B.** [US/US]; 37 Third Street, Towanda, Pennsylvania 18848 (US).
- (74) Agent: **CASTEL, Benoit**; c/o YOUNG & THOMPSON, 745 South 23rd Street, Suite 200, Arlington, VA 22202 (US).
- (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.
- (84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: TUNGSTEN-BASED ELECTROCATALYST AND FUEL CELL CONTAINING SAME



(57) Abstract: The catalyst of this invention is a non-stoichiometric tungsten compound,  $H_{0.53}WO_3$ , which may be used as both the anode and cathode electrocatalyst for acid-style low-temperature fuel cells. A fuel cell using the tungsten-based electrocatalyst as both the anode and cathode has been constructed and operated with a hydrogen fuel and an air oxidant.

WO 2004/088780 A1

**Published:**

- with international search report
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

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JC05 Rec'd PCT/PTO 26 SEP 2005

Tungsten-based Electrocatalyst and Fuel Cell Containing Same

CROSS REFERENCES TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional

5 Application No. 60/320,056, filed 3/26/2003.

TECHNICAL FIELD

This invention relates to electrocatalysts for fuel cells.

10 More particularly, this invention relates to tungsten-based electrocatalysts for low-temperature fuel cells.

BACKGROUND ART

Fuel cells produce electricity by converting reactants such as hydrogen, hydrocarbons, and oxygen into products such as water and carbon dioxide. In its simplest form, a fuel cell  
15 comprises an anode and cathode separated by an electrolyte. The anode and cathode consist of a conductive support, usually carbon black, having a thin layer of a platinum catalyst that is uniformly dispersed over the surface of the support. In a  
20 proton-exchange membrane (PEM) fuel cell, the electrolyte is a solid polymeric material capable of conducting protons, e.g., a perfluorosulfonic acid polymer (e.g., Nafion® by DuPont). Examples of these devices are described in U.S. Patent Nos. 6,030,718, 6,040,007 and 5,945,231 which are incorporated  
25 herein by reference.

During operation, a continuous flow of fuel, e.g., hydrogen, is fed to the anode while, simultaneously, a continuous flow of oxidant, e.g., oxygen or air, is supplied to the cathode. In  
30 the case of a hydrogen fuel, hydrogen gas is oxidized with the aid of a platinum catalyst at the anode to generate electrons and protons which travel by separate paths to the cathode. The

electrons are conducted through an external circuit and the protons are conducted through the electrolyte. At the cathode, oxygen gas combines with the electrons and protons to produce water, again with the aid of a platinum catalyst. The current generated by the electrons flowing through the external circuit can be used for work.

Platinum catalysts are preferred for fuel cells because of their high electrochemical activity. However, platinum is expensive and easily poisoned by the trace amounts of carbon monoxide typically found in hydrogen fuels. Numerous attempts have been made to find less expensive electrocatalysts or reduce the sensitivity of platinum catalysts to carbon monoxide. Several of these attempts have focused on tungsten and molybdenum compounds, and in particular their carbides and oxides. In 1965, AEG-Telefunken discovered that tungsten carbide could potentially replace platinum as an anode catalyst for acid-style fuel cells. These investigators ran a fuel cell for over 30,000 hours with an anode catalyst composed of tungsten carbide. Since that time, five more tungsten compounds have been identified as potential anode and cathode catalysts for low-temperature acid-style fuel cells: WC, W<sub>2</sub>C, WO<sub>3</sub>:Pt, Na<sub>x</sub>WO<sub>3</sub>, W-POM. For example, U.S. Patent No. 5,922,488 describes a CO-tolerant anode catalyst which uses a carbon-supported, platinum-dispersed, non-stoichiometric hydrogen tungsten bronze having the formula Pt-H<sub>x</sub>WO<sub>3</sub> wherein x ranges from about 0.05 to about 0.36. U.S. Patent No. 5,298,343 describes a polycomponent electrocatalyst comprised preferably of platinum or palladium and a chemical component selected from the group consisting of tungstic acid, molybdic acid, ammonium tungstate, ammonium molybdate, sodium tungstate and sodium molybdate. U.S. Patent No. 5,945,231 contemplates combining

tungsten carbide with ruthenium oxide or ruthenium to form a catalysts for a direct liquid-feed fuel cell. Unfortunately, these tungsten and molybdenum-based catalysts have not been shown to exhibit an acceptable level of electrochemical activity for practical fuel cell application without the additional presence of a platinum group metal (platinum, ruthenium, or palladium) co-catalyst.

#### SUMMARY OF THE INVENTION

It is an object of the invention to obviate the disadvantages of the prior art.

It is another object of the invention to provide a tungsten-based electrocatalyst for fuel cells.

It is a further object of the invention to provide a fuel cell that has a tungsten-based electrocatalyst that functions as both the anode and cathode catalyst without having to employ a platinum group metal co-catalyst.

In one aspect, the catalyst of this invention is a non-stoichiometric tungsten-based compound,  $H_{0.53}WO_3$ , which may be used as both anode and cathode electrocatalyst for acid-style low-temperature fuel cells.

In another aspect, the method used to make the catalyst is a novel route to hydrogen tungsten bronze which involves first creating an ammonium bronze,  $(NH_4)_{0.33}WO_3$ . This material is stable and is formed by heating ammonium metatungstate at about 490°C in an inert atmosphere. Preferably, the ammonium metatungstate (AMT) is dehydrated prior to heating at about 490°C. Dehydration may be achieved by heating the AMT at a

temperature from about 120°C to about 200°C. Dehydration is complete when the AMT achieves a green color. This method has many practical improvements in the art, including eliminating extra water and oxygen from the compound, and forming a stable  
5 intermediate for further catalyst synthesis. This intermediate can also be applied to synthesis for other tungsten-based catalyst applications, including hydrocracking and NO<sub>x</sub> control catalysts. The electrocatalytic hydrogen bronze, H<sub>0.53</sub>WO<sub>3</sub>, is formed by heating the ammonium bronze in a mixture of hydrogen  
10 and an inert gas, e.g., argon.

In a further aspect of the invention, there is provided a fuel cell which employs a tungsten-based electrocatalyst as both the anode and cathode.

15

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an x-ray diffraction pattern of the catalyst of this invention.

20 Fig. 2 is a plot of the half-cell performance of the catalyst of this invention.

Fig. 3 is a graph of the voltage-power performance of a fuel cell wherein both the anode and cathode are comprised of the  
25 tungsten-based catalyst of this invention.

Fig. 4 is a graph of the operational performance of a fuel cell at various resistive loads wherein both the anode and cathode are made with the tungsten-based catalyst of this invention.

30

Fig. 5 is an exploded cross-sectional illustration of a PEM-type fuel cell employing the catalyst of this invention.

DETAILED DESCRIPTION OF THE INVENTION

For a better understanding of the present invention, together with other and further objects, advantages and capabilities thereof, reference is made to the following disclosure and appended claims taken in conjunction with the above-described drawings.

The tungsten-based catalyst of this invention was synthesized and tested by XRD, voltammetry, and fuel cell operation. Fig. 1 shows the X-ray powder diffraction pattern of the carbon-supported tungsten-based electrocatalyst. The diffraction pattern fits the X-ray powder diffraction file, PDF 72-1712, for  $\text{H}_{0.53}\text{WO}_3$ . This material creates a unique foundation for electrocatalysis for several reasons: (1) the material is electrically conductive; (2) the structure of the material includes a more open lattice than other tungsten materials; (3) the nonstoichiometric nature creates a mixed-valence compound with complete electron delocalization over the cation ion lattice; and (4) cyclic voltammetry shows that this hydrogen bronze has catalytic behavior for both hydrogen oxidation and oxygen reduction. Fig. 3 shows the performance of a fuel cell wherein both the anode and cathode have been fabricated with the tungsten-based catalyst of this invention.

An exploded cross-sectional illustration of a PEM-type fuel cell employing the catalyst of this invention is shown in Fig. 5. At the center is a polymer membrane 7, preferably a perfluorosulfonic acid polymer (e.g., Nafion<sup>®</sup> by DuPont). Adjacent to the polymer membrane 7 are the catalyst layers 4. Here, unlike conventional fuel cells, the catalysts layers 4 both contain a tungsten-based electrocatalyst,  $\text{H}_{0.53}\text{WO}_3$ ,

dispersed on a carbon black support, preferably about 20% tungsten by weight. Layers of carbon paper 9 are applied on either side of the catalyst layers 4. The multiple layers are bonded together to form a membrane-electrode assembly 2. Gas distribution plates 5 are used to deliver the H<sub>2</sub> fuel and air oxidizer to either side of the membrane-electrode assembly 2.

The following non-limiting examples are presented.

10

## EXAMPLE 1

15

Three carbon rods (Bay Carbon AGKSP 0.242x12) were soaked in a solution of ammonium metatungstate (AMT) (OSRAM SYLVANIA, catalyst grade, 1600g/l) for three days. The rods were placed in a 9" Inconel boat, along with a small amount of AMT in a graphite boat as a visual indicator. The boats were placed in a tube furnace and sealed at a pressure of 5 inches water gauge in flowing Argon.

20

The furnace was heated to 200°C and held until the AMT powder appeared green, indicating the material had dried. The temperature was raised to 490°C under argon and held overnight. The samples appeared dark blue, indicating that an ammonium tungsten bronze had formed.

25

30

The gas flow was changed to 1 lpm H<sub>2</sub> and 1 lpm Ar to provide a partially reducing atmosphere. The appearance of the material was monitored, and the AMT sample appearance changed color with a moving interface, changing from blue to gray. After 7.5 hours, the furnace was cooled. The furnace was purged and the samples removed for analysis. Fig. 2 shows the anodic half-cell performance characteristic for this sample in 0.5M H<sub>2</sub>SO<sub>4</sub> in



bubbling hydrogen. The performance of a comparatively loaded supported platinum electrode is shown for comparison. The inverted curve of the hydrogen bronze catalyst suggests that the kinetics are slower in the region near zero overpotential, however, mass transfer limited currents (above 0.5V) were similar.

## EXAMPLE 2

- 10 Four carbon rods (Bay Carbon AGKSP 0.242x12) were soaked in a solution of ammonium metatungstate (AMT) (OSRAM SYLVANIA, catalyst grade, 1600g/l) for three days. The rods were placed in a 9" Inconel boat, along with two other boats, one ceramic boat containing AMT on a high-surface-area carbon powder
- 15 (20wt.% W), Cabot XC-72, and one ceramic boat containing a small amount of AMT as a visual indicator. The boats were placed in a tube furnace and sealed at a pressure of 5 inches water gauge in flowing Argon.
- 20 The furnace was heated to 120°C and held until the AMT powder appeared green, indicating the material had dried. The temperature was raised to 490°C under argon and held overnight. The samples appeared dark blue, indicating that an ammonium tungsten bronze had formed.
- 25 The gas flow was changed to 1 lpm H<sub>2</sub> and 3.5 SCFH Ar to provide a partially reducing atmosphere. The appearance of the material was monitored, and the AMT sample appearance changed color with a moving interface, changing from blue to gray.
- 30 After 1.75 hours, the furnace was cooled. The furnace was purged and the samples removed for analysis. X-ray diffraction

of the material from the center boat, which began as AMT on carbon black (20 wt.% W ), showed the material to be  $H_{0.53}WO_3$ .

## EXAMPLE 3

The tungsten bronze supported on carbon black from Example 2 was fabricated into a 5cm<sup>2</sup> membrane electrode assembly (MEA).

5 The cathode and anode were constructed by teflon-bonding the supported tungsten-based catalyst to form a 5-layer MEA with carbon paper and a Nafion<sup>®</sup> 117 membrane. These were then assembled into a 5cm<sup>2</sup> fuel cell and operated with hydrogen and air at room temperature and 50°C with various fixed resistive  
10 loads to obtain the summarized operation curves in Fig. 3. Fig. 4 shows the raw data of applied load and voltage observed over time. Temperature was controlled by heating the cell with surface heaters and a temperature controller with a K-type thermocouple inserted in the cell's thermal well. These  
15 results demonstrate that it is possible to construct an operating fuel cell with only a tungsten-based electrocatalyst and without having a platinum group metal in either the anode or cathode.

20 While there has been shown and described what are at the present considered the preferred embodiments of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the scope of the invention as defined by the appended  
25 claims.

CLAIMS

I claim:

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1. A tungsten-based catalyst for a fuel cell comprising  $H_{0.53}WO_3$  dispersed on a catalyst support.

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2. The catalyst of claim 1 wherein the catalyst support is carbon black.

3. The catalyst of claim 2 wherein the catalyst contains about 20% tungsten by weight.

15

4. A method of making a tungsten-based catalyst for a fuel cell, comprising:

(a) heating ammonium metatungstate in an inert atmosphere to form  $(NH_4)_{0.33}WO_3$ ; and

20

(b) heating the  $(NH_4)_{0.33}WO_3$  in a hydrogen-containing atmosphere to form  $H_{0.53}WO_3$ .

5. The method of claim 4 wherein the ammonium metatungstate is heated at about 490°C.

25

6. The method of claim 5 wherein the ammonium metatungstate is dehydrated prior to heating at about 490°C.

7. The method of claim 6 wherein the ammonium metatungstate is dehydrated at a temperature from about 120°C to about 200°C.

30

8. The method of claim 5 wherein prior to heating the ammonium metatungstate has been dispersed on a carbon black support.

5 9. The method of claim 8 wherein after the ammonium metatungstate has been dispersed on the support, the support contains about 20% tungsten by weight.

10 10. A fuel cell comprising an anode and a cathode wherein the anode and cathode are comprised of an electrocatalyst which consists essentially of a tungsten-based electrocatalyst.

15 11. The fuel cell of claim 10 wherein the tungsten-based electrocatalyst is  $H_{0.53}WO_3$  dispersed on a carbon black support.

12. The fuel cell of claim 11 wherein the electrocatalyst contains about 20% tungsten by weight.

20 13. The fuel cell of claim 11 wherein the anode and cathode are separated by a polymer membrane.

14. The fuel cell of claim 13 wherein the polymer membrane is a perfluorosulfonic acid polymer.

25 15. The fuel cell of claim 14 wherein the fuel cell uses hydrogen as a fuel and air as an oxidant.

16. The fuel cell of claim 10 wherein the fuel cell is a PEM-type fuel cell.

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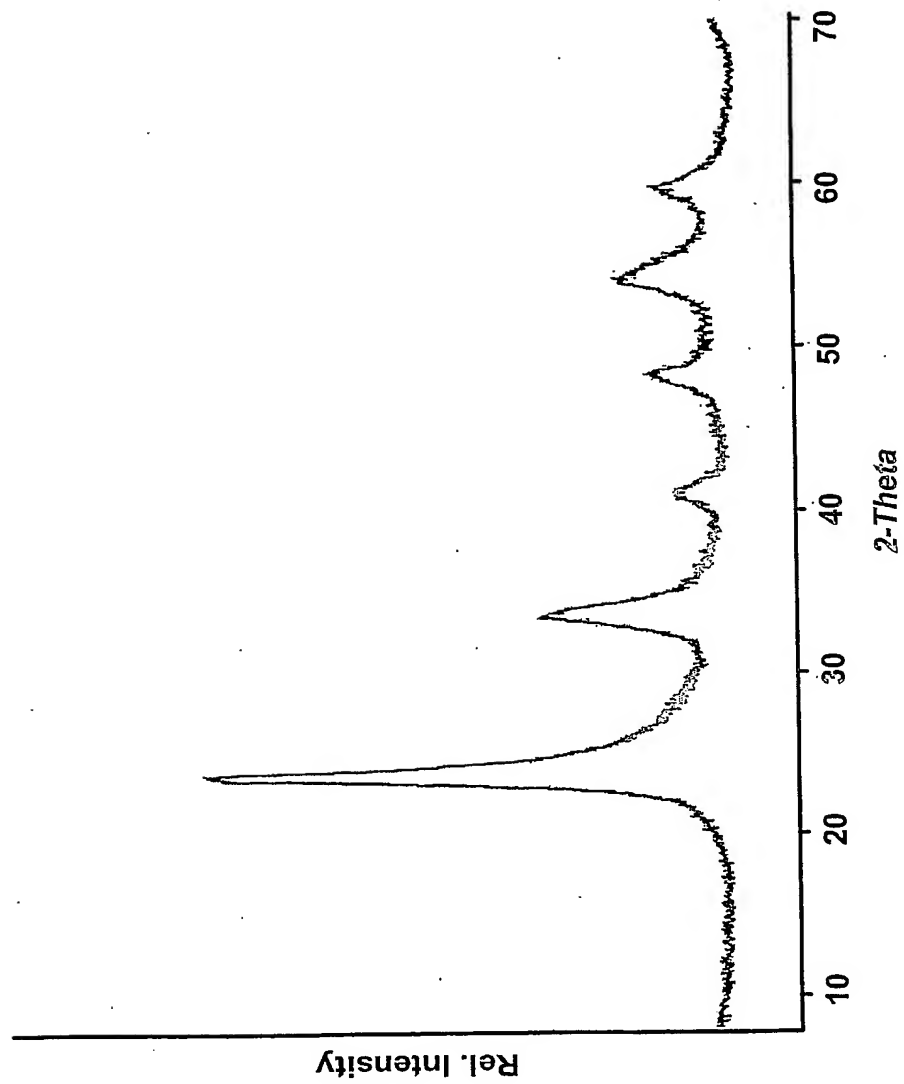


FIG. 1

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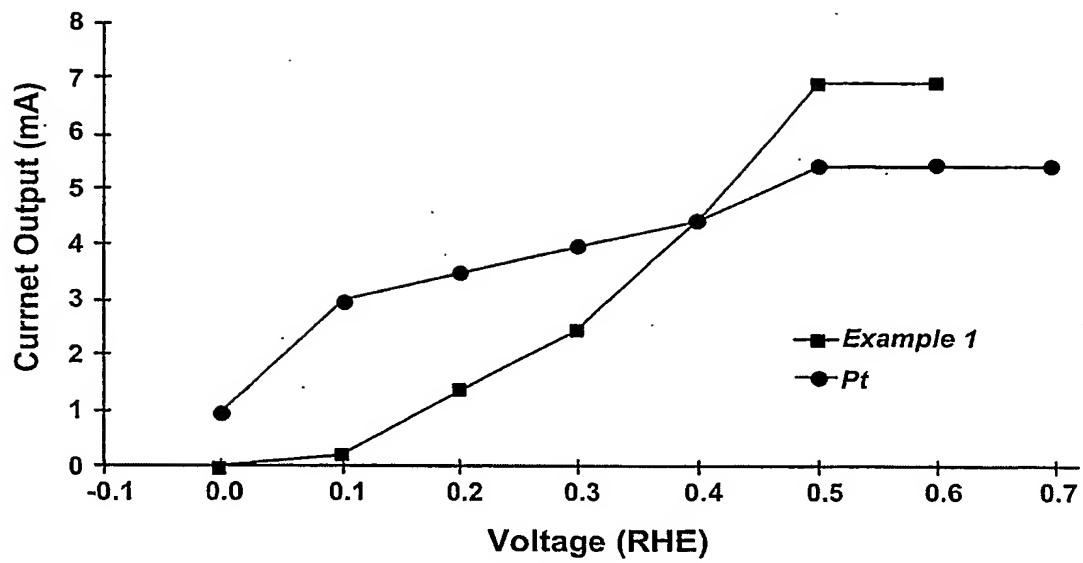


FIG. 2

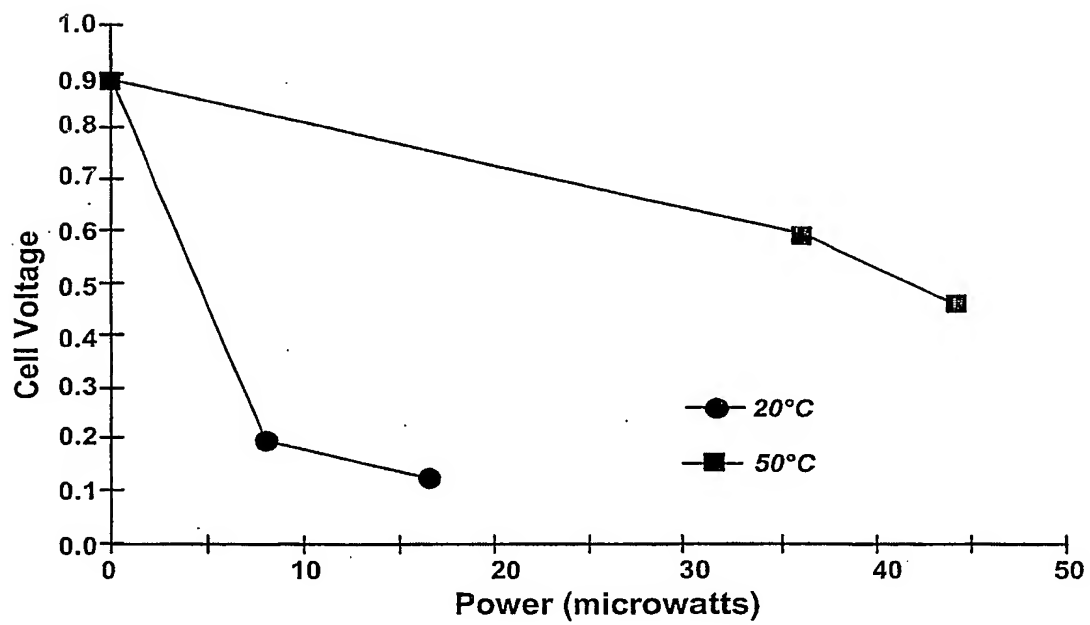


FIG. 3

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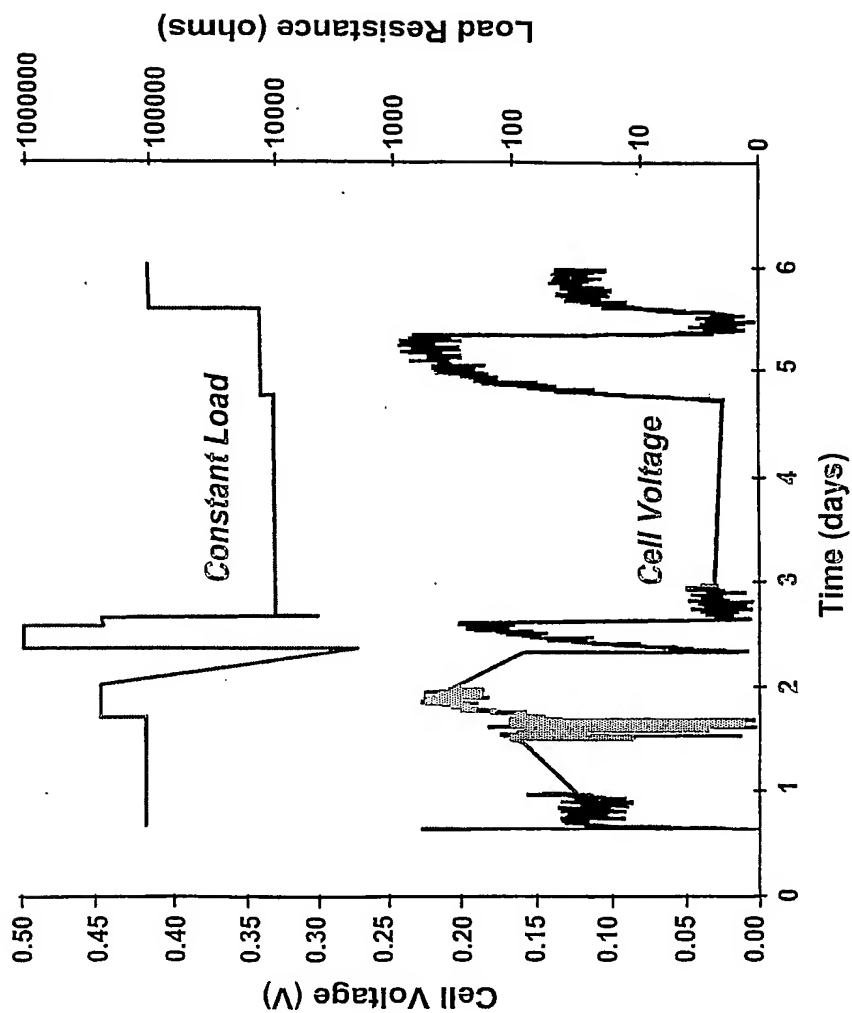
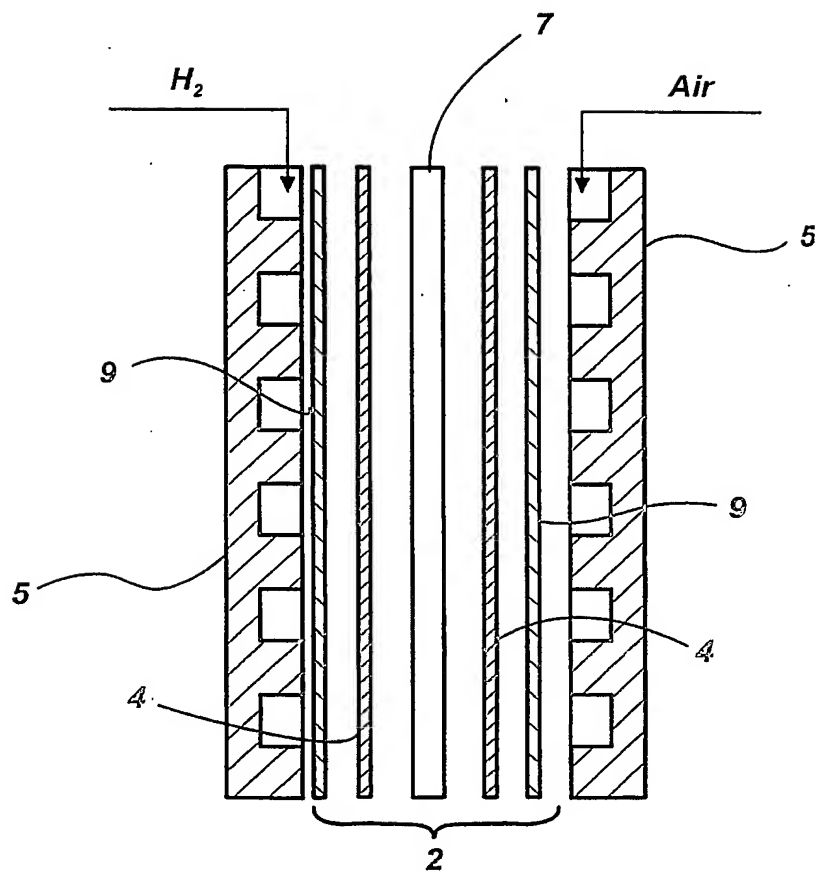


FIG. 4



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**Fig. 5**

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US04/09019

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : H01M 8/02, 4/90; C01G 41/02; B01J 23/30  
US CL : 429/40, 44; 423/606, 502/182, 305

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
U.S. : 429/40, 44; 423/606, 502/182, 305

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
Please See Continuation Sheet

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,910,181 A (ANGEVINE et al) 20 March 1990, see column 3, lines 9-30.	1 ----- 2, 3
Y	US 2002/0111267 A1 (CHRISTIAN et al) 15 August 2002, see paragraphs 25 and 34.	2, 3, 10, 16
Y	US 3,507,701 A (BROYDE) 21 April 1970, see abstract; column 2, line 20.	10, 16
A	US 4,339,424 A (JACOBSON et al) 13 July 1982, see column 2, lines 42-59.	4-9

☐ Further documents are listed in the continuation of Box C.

☐ See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance  
"E" earlier application or patent published on or after the international filing date  
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)  
"O" document referring to an oral disclosure, use, exhibition or other means  
"P" document published prior to the international filing date but later than the priority date claimed

"T"

later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X"

document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y"

document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&"

document member of the same patent family

Date of the actual completion of the international search

Date of mailing of the international search report

19 July 2004 (19.07.2004)

10 AUG 2004

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Mail Stop PCT, Attn: ISA/US  
Commissioner for Patents  
P.O. Box 1450  
Alexandria, Virginia 22313-1450  
Facsimile No. (703) 305-3230

Jonathan S. Crepeau

Telephone No. (571) 272-1700

# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US04/09019

## Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claim Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claim Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐

The additional search fees were accompanied by the applicant's protest.

☐

No protest accompanied the payment of additional search fees.

**INTERNATIONAL SEARCH REPORT**

PCT/US04/09019

**Continuation of B. FIELDS SEARCHED Item 3:**

USPT, USPGPUB, EPAB, JPAB, Derwent, HCA

search terms: tungsten, hydrogen, bronze, cataly\*, support\*, carbon\*, ammonium, metatungstate